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SIMPLIFY FIRST: A MODERNIZATION STRATEGY FOR DoD MAINTENANCE DEPOTS

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Executive Summary

SIMPLIFY FIRST: A MODERNIZATION STRATEGY FOR DoD MAINTENANCE DEPOTS

DoD maintenance depots are under intense pressure to increase productivity while maintaining a robust capability for mobilization tasks. At the same time, capital investment funding, a key ingredient in the depots' productivity-enhancing initiatives, is decreasing.

The depots can best resolve this situation by adopting a modernization strategy that focuses first on simplifying processes and only later on introducing automated production and inventory controls or process automation. Such a strategy is well proven in both the private sector and DoD. It uses current assets more productively and provides a sharper focus for capital investments.

Simplification of repair or fabrication processes nearly always results in both immediate and long-lasting productivity gains and requires little, if any, net capital investment. Simplification takes many forms; one is illustrated by the application of group technology and cellular organization to the engine shop at Oklahoma City Air Logistics Center, another by the integration of inventory management and maintenance scheduling at a major commercial airline. All experience shows that simplified processes substantially reduce depot turnaround times and operating costs. Simple processes are also easier to understand, which permits better planning for, and response to, mobilization.

With a coherent modernization strategy, starting with simplification, DoD maintenance depots will be better able to meet their productivity goals. Current assets will be used as efficiently as possible, and capital investments will be targeted to areas that have maximum effect on productivity and capability.

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CHAPTER 1

INTRODUCTION

STATEMENT OF THE PROBLEM

The Military Services are under substantial pressure to increase the productivity of their maintenance depots while maintaining a robust capability to meet mobilization requirements. The impetus for increasing depot productivity is to comply with the President's goal of a 20 percent productivity improvement by FY92.[1]

Funds for capital investment in the depots are "drying up." Traditionally, investment has been the key ingredient in productivity-enhancing initiatives. Therefore, the problem that the depots face is how to make major productivity gains with very little capital investment. To do that, they must achieve significantly greater productivity gains from capital investments than they have in the past; business as usual will not suffice.

Although this problem may be approached by changing the depot structure as a whole (e.g., redefining the missions of the depots, consolidating depots and workloads, putting all work on contract), we confine ourselves in this report to an approach that focuses on how the individual depot, given its current mission, can increase productivity and retain mobilization capability without massive capital investment.

Let us first examine the physical and budgetary environments in which the depots operate, next explain the concept of a modernization strategy, and then briefly state why we think that the modernization strategy proposed in this report may help solve this seemingly intractable problem of doing so much more with so much less.

[1]In order to meet the President's goal, a 3 percent average annual rate of increase in labor productivity is needed over the FY86 to FY92 period. According to the Bureau of Labor Statistics, labor productivity in equipment maintenance Government-wide (primarily DoD) has shown an improvement of only 1.8 percent per year over the period FY80 through FY86.[1]

DEPOT ENVIRONMENT

The major characteristic that determines the environment of DoD depots is that they primarily perform maintenance, not manufacturing. The import of this is that the "raw material" of a depot is often an item in an unknown state of disrepair. Thus, the first steps in the maintenance process must be inspection and diagnosis, just to determine what needs to be done. Items that are otherwise identical may require widely differing repairs because of differences in their conditions. Compounding this situation is the uncertainty of what kinds of items will be entering the depot. The items to be repaired vary according to what is breaking or wearing out in the field and currently cannot be confidently predicted.

To cope with the variable nature of the work, depots, for the most part, are organized as job shops. That is, they perform the work in functionally oriented shops (e.g., a lathe shop, a sheet metal shop) rather than in product-oriented production lines. The most salient characteristic of a job shop, be it in a Government depot or in private industry, is that at least 95 percent of the time an item is in a job shop it is either moving from one shop to another or waiting to be worked on [2,3]. At most, only 5 percent of the time that an item is in a job shop is it actively being worked on. For instance, a turbine blade must first be inspected, then machined, "built," and finally machined again. With separate shops for each of these functions, the turbine blade has to be moved three times between the shops – with additional setups for the machines – and that takes a great deal of time.

In addition, the location and repair status of an item is difficult to track while that item is moving between shops (part routing). Because the routing for a particular part (and its bill of materials) is not fixed over time but varies according to its operational usage and attendant repairs, the job of keeping track rapidly becomes unmanageable. Complex routings not only pose a problem for efficiency in peacetime but increase the difficulty in planning for mobilization tasks.

Another characteristic of a job shop is that quality is difficult to control, much less continually improve. Because parts move through a series of functional shops for repairs, no single supervisor is responsible for a particular part. If the repaired part has a quality problem, the functional shop responsible for the problem cannot readily be identified and a long-term solution is virtually impossible.

Thus, the job shop environment often results in long depot turnaround times, high work-in-process inventories, and difficulty in meeting schedules. All these factors raise the cost of operations.

BUDGET ENVIRONMENT

The budget environment affects the depots by determining how much money their customers have available to buy the depot's services and how much money the depots have available to make capital investments.

Compounding the uncertainty already inherent in a maintenance environment is the uncertainty in the overall level of funding for depot maintenance. Smaller budgets for the customers of the depots have contributed to declines in depot workloads. For example, Oklahoma City Air Logistics Center (OCALC) will be working on under 1,100 complete engines in FY88, almost 300 less than in FY87. In parts of Norfolk Naval Aviation Depot, a 22-year low in workload will be reached in FY89. Similar reductions in workload are occurring in Army depots and in Navy shipyards.

The budget for modernizing DoD maintenance depots also is decreasing. In recent years, funds for facilities – both Military Construction and minor construction funds – have been curtailed. For example, the Navy's home-porting initiative has virtually precluded the availability of Military Construction funds for major construction projects in Navy shipyards and aviation depots between FY87 and FY89. Funds for equipment are also decreasing. In the Air Force, for example, the Asset Capitalization Program in FY89 will not keep pace (as it was designed to) with the depreciation of existing equipment, much less finance any extensive modernization initiatives.

In short, funds for major new capital investments in the depots have been decreasing. What is more, given the current Federal deficits, the funding picture for DoD depots is unlikely to improve very much in the near future.

In this restrictive budgetary environment, it is essential that the depots develop modernization strategies that can better reconcile their need for improvement in maintenance depot productivity with the current budget realities.

CONCEPT OF A MODERNIZATION STRATEGY

A modernization strategy is a logical framework for setting priorities for introducing technology and making capital investments. The result is an integrated series of actions and investments that maximize depot performance.

A modernization strategy begins with existing processes and their current use of resources. By focusing on processes, rather than on physical assets, it may be possible to discover a better way to combine existing equipment and labor on the shop floor. Improvements in processes may dramatically increase the performance of the existing physical resources. Once the improved process is in place, further improvements in operations may require capital investments for building facilities, buying equipment, automating the control of production and inventory, and automating production itself. All those investments, however, still focus on the process.

A modernization strategy links the improved process and all follow-on capital investments into an integrated, time-phased, operational whole. Considerable synergistic benefits can result from improving the process and from planning a series of coordinated capital investments. Without that well-integrated modernization course of action, capital investment decisions tend to be made on a case-by-case basis and the important synergistic benefits are lost.

A modernization strategy helps determine the types of capital investments needed but not the specific capital investments themselves. It helps define the next general focus for capital investments in the depot, such as, introducing automated inventory and production control. However, to make a specific capital investment that fits this focus, an economic analysis is still needed to select the "best" alternative among the possibilities that are available.

A modernization strategy fits the limited capital investment budget levels available. Thus, at least initially, the elements of depot modernization strategy must be capable of delivering major benefits at modest levels of funding.

The modernization strategy that we recommend in this report would do all of the above by first focusing on simplifying the processes used in the depots. This process simplification directly attacks the difficulties of a job shop by concentrating attention on the 95 percent of the time that a part is idle rather than on the 5 percent

that it is being worked on. The processes can be simplified with very little capital investment. The modernization strategy then targets capital investments to areas in which they will have the greatest payoffs.

ORGANIZATION OF REPORT

This report proposes a basic modernization strategy for the maintenance depots.

Chapter 2 presents that strategy. The findings supporting the strategy are presented in succeeding chapters: Chapter 3, examples where elements of this strategy are being used in DoD, and Chapter 4, lessons learned from the private sector.

Two technical issues are examined in the appendices. Appendix A covers group technology and cellular repair, and Appendix B discusses automated control of inventory and production.

CHAPTER 2

MODERNIZATION STRATEGY

Simplify processes first. That, in a nutshell, is the foundation for our modernization strategy for the depots. It means that the process should be simple enough that the line worker knows what the task is, how it should be done, how it can be improved who the customer is, and what that customer wants. Also, it means that the manager can readily assess the process, set priorities, and identify the source of problems without recourse to complex, usually dated reports. Simplified processes clearly show who is in charge of the process, what the product is, and who has responsibility for its quality.

SIMPLIFYING THE PROCESS

The benefits of simpler processes are especially evident when compared with a functionally oriented job shop environment. Those benefits are decreased depot throughput time, reduced work in process inventory, improved product quality, and better adherence to production schedules. The result is decreased cost of operation, increased responsiveness to the customer, and better planning for and execution of mobilization workloads.

Simplification has the greatest impact when production is characterized by complex routings, diverse product lines, and variable inputs (i.e., variable in condition – the kind of repairs required – and in type – the products that make up the workload). Some processes in DoD depots are already "simple" in this sense. For example, in bench repair of electronics, most of the time is spent in testing, and all subsequent repair is done by a single technician at a bench; bench repair does not require complex routings and is dedicated to a particular product. However, even in this example, further simplification might be achieved by moving from complex, multipurpose automated test equipment to simpler, dedicated test equipment.

In contrast, other processes, such as those employed in overhauling jet engines, are extremely complex and have great potential for simplification. Still other processes, such as repairs done aboard ships, may need to be simplified by managing labor differently. Aboard ship, the process could be simplified by using a single team

to inspect for discrepancies and having the same team determine, authorize, and perform the needed repairs. A team approach has been successfully used to perform ship repairs at sites outside the shipyards.

The techniques for simplifying processes are based on eliminating the sources of complexity. One source of complexity – multiple product lines – can be simplified by reducing the number of different items a depot repairs, creating product families that have similar setup and equipment requirements, and using simple, dedicated machines instead of complex, multipurpose machines. Other simplification techniques center on reducing the variability of the inputs by knowing when and in what condition items will enter the depot, increasing the quality of repair parts, and making the supply of repair parts more predictable. All of these techniques for process simplification increase the performance of depot maintenance resources.

Repair Cells

Another source – complex routings – occurs when the repair process has multiple steps that are performed in physically separate, functionally oriented shops. To eliminate complex routings, and thus simplify the process, all of the steps need to be performed in the same location. This can be done by combining into a single shop all of the machines and people needed to perform each step of the process. We call such a process-dedicated shop a *repair cell.*

Repair cells are an excellent way to simplify processes that have complex routings. The problem of moving parts long distances between machines in different shops can be solved by reorganizing the shop floor from a functional layout into cells that are dedicated to the production of particular parts. Under a functional layout, all grinding machines in a depot are physically grouped together in one area and all welding machines are grouped together in another area. In contrast, a cellularly organized depot locates all of the different kinds of machines needed for repairing a particular part together – grinding machines and welding machines would be found in all cells requiring those functions.

As a result, parts move very differently between the two types of shop floor layouts. Under the functional layout, parts have to move from shop to shop to

complete their repairs, often traveling long distances (in some cases miles); under the cellular layout, a part is repaired within a single cell.

Cellular organization has several important benefits. The movement of parts and machine setup times are radically reduced – and that reduces transfer times, waiting times, and work-in-process inventories. The responsibility and authority for producing the parts in the cell rests with a single supervisor who can trace problems and set priorities much more successfully than his analog in a functional shop.

Repair cells also complement the use of Total Quality Management in the depot. Total Quality Management needs a process that fosters continuous improvement. In a repair cell, the worker has more immediate feedback on the quality of his work because he knows his "customer" – the worker doing the next step in the process in his cell. The cell also offers a logical setting for a quality circle because all the steps in the process are controlled by those working in the cell. Finally, because a family of parts is repaired in the cell (and, therefore, the individual parts share similar characteristics), more use can be made of quality-improvement tools such as Statistical Process Control.

These process-improving benefits can be achieved with little expenditure. Costs are incurred in planning for the reorganization of the shop floors (use of available planning tools reduce this cost) and for moving the machinery. The potential cost of lost production from disruption can usually be minimized by phasing-in the cellular organization. In many cases, however, all of these costs are offset by the value of equipment that is found to be surplus to the process. In all cases that we reviewed, the conversion of a functional organization to a cellular organization considerably reduced the number of pieces of equipment needed in the process. If the value of that equipment is reflected in the cost calculation, then the net (economic) cost of creating the cell is near zero.

Repair cells can dramatically simplify repair processes that have complex routings. They have significant operational and management benefits. They do not require heavy capital investment and are inexpensive to implement. Therefore, repair cells could be implemented with significant benefits in a wide range of depot applications.

Part Families

Proponents for a functional organization could argue that in the depot, no part is produced in sufficient volume to require a dedicated series of machines. That is true for a single part; therefore, families of parts need to be defined to create sufficient volume to support a cell. Group technology is a method for identifying parts that undergo similar industrial processes and for grouping those process-related parts into "part families." For example, a part family might consist of all combustor cans for jet engines or all cylindrical metal parts less than 6 inches in diameter. A cell can then be created that processes an entire part family, thus providing the volume necessary to justify dedicated machines in that cell.

Specialization

If the formation of part families still fails to provide enough volume to create cells, the depot could seek to specialize; it could repair fewer product lines but increase the volume in each line repaired. That action would be designed to increase the volume in particular part families. Workload in the depots would have to be reallocated to achieve specialization by part families. The specialization of workload by part families could provide sufficient volumes to justify many cellular operations throughout the DoD depot maintenance structure.

Private industry has often created cellular operations by specializing factory workloads by part families. In jet engine manufacturing, such specialization results, for example, in one factory producing only turbine disks. That specialization then allows cellular organization within the factory.

Overview

Simplifying the process increases the performance of existing physical assets. With simplification capital investments can be targeted to where they offer the greatest benefit. Depots should focus on two areas in particular: production and inventory control, and process automation.

PRODUCTION AND INVENTORY CONTROL

Improvement in production and inventory control is best accomplished by eliminating as much inventory as possible and by scheduling production to meet known demand. In the manufacturing world, companies use Just In Time (JIT)

production techniques for that control. In our opinion, JIT, in its purest form, will probably not meet all of the depot's requirements. JIT *per se* does not adequately address two key characteristics of the depot environment: uncertainty – demand, part condition, and repair part availability, are not known precisely – and complexity – the repair process includes disassembly, inspection, repair, and assembly, whereas the manufacturing process includes only fabrication and assembly. However, the JIT goals of eliminating unnecessary inventory and not producing more than is needed are still valid for the depots, as are some of the JIT techniques, most notably, simplifying processes.

Simplified processes require less control and tracking because the routing of parts between shops and the work-in-process inventory are reduced. Furthermore, the simplified process make data collection easier, resulting in greater data accuracy – an important requirement for these automated systems.[1]

Because the repair process is complex and uncertain, even after simplification, inventory will remain and need to be controlled. Furthermore, specific processes, such as plating, cannot be duplicated in every repair cell for cost, safety, and environmental reasons. Those processes will require sophisticated scheduling so that they do not become bottlenecks.

American industry has used Manufacturing Resource Planning (MRP-II) for inventory and production control. However, 90 percent of the private sector users of this kind of system are unhappy with its results [5]. The primary reason is that MRP-II requires a very high degree of accuracy in part routing and bills of materials – 95 percent accuracy or better – and that degree of accuracy is very difficult to attain. If this is true in manufacturing, it will be true all the more in repair, particularly if processes are not first simplified. Nevertheless, the Air Force is starting a pilot implementation of MRP-II and the other Military Services are considering it.

Other systems for automating the control of inventory and production are coming into use in manufacturing. Optimized Production Technology, for instance, optimizes total production by concentrating on scheduling bottlenecks. (In Appendix B, we compare Optimized Production Technology with MRP-II.) However,

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[1]Conversely, trying to simplify processes after inappropriate automated controls have been introduced is very difficult [4].

off-the-shelf products developed for the manufacturing environment need to be supplemented with extensive, custom software development to make them work in a repair environment. That is why automating the control of production and inventory for the maintenance depots is so expensive. The estimated cost of implementing MRP-II in the depots is close to $500 million.

AUTOMATION

Flexible Manufacturing Systems, robotics, Computer Integrated Manufacturing, and other types of automation can be applied successfully to production under certain circumstances. Automation requires that tasks be reasonably repetitive and that volumes be sufficiently high. It can also remove workers from direct contact with hostile environments, thus increasing safety in the work place.

In a functionally organized job shop, the requirements for successful automation are especially difficult to meet. The numerous, complex routings and variable nature of the work seldom permit the appropriate degree of repetitiveness, nor is the volume of work sufficient for the successful introduction of automation. The complex process also makes it difficult to assess which operations are likely to benefit from automation and which are not.

By contrast, in a cellularly organized job shop, the requirements for a successful application of automation are much more likely to be met. There, the process is simplified so that narrower groups of parts are worked on within a cell. The effect of focusing on subsets of parts is to increase the degree of repetitiveness – in at least some part of the cell – and to increase the volume of work. Also, by working with a simpler, more easily understood process, operators can develop the needed tooling and fixturing to improve upon the setup times of machines – an essential element for successful automation.

Automation is an expensive proposition. For example, the new blade facility at OCALC cost about $60 million to construct and equip; $19 million – or more than 30 percent – of that cost is accounted for by a highly automated integrated welding and grinding cell alone. A single robotic application can cost $2 million or more. Process automation will be difficult to afford as capital investment funding decreases. It will make the greatest impact if it follows process simplification.

SUMMARY

A modernization strategy appropriate for DoD maintenance depots is to simplify processes and then, where necessary, introduce automated production and inventory controls, followed by process automation. That strategy will increase performance of existing assets and target application of future resources.

This basic modernization strategy approach is substantiated quite strongly in some of DoD maintenance depots and in the private sector, as described in Chapters 3 and 4. The potential benefits of following this strategy are so high and the cost so low that it should be applied in all settings in which it is applicable.

No single, detailed modernization strategy will be effective for all of the diverse organizations that make up the DoD depot maintenance community. However, we believe that the basic strategy presented here will help guide the depots in productive directions by addressing the very real problem of increasing productivity while capital investment decreases.

CHAPTER 3

DoD APPLICATIONS OF MODERNIZATION STRATEGY

OKLAHOMA CITY AIR LOGISTICS CENTER

In 1985, OCALC simplified its process for repairing and overhauling aircraft engines by applying the principles of Group Technology (GT) and cellular organization. (Appendix A presents the technical underpinnings of GT and cellular organization.) That simplification has resulted in major gains in both productivity and efficiency.

As early as 1982, OCALC had introduced GT and cellular organization in its propulsion division for the repair of combustion cans and turbine exhaust cases. In 1984, a major fire in the building that housed the propulsion division caused a disruption of production and the removal of all of the equipment from the affected areas of the building. This gave OCALC an opportunity to reorganize a major portion of its propulsion division (more than 1,300 people and 850 machines) and simplify the process by using GT and cellular organization; it accomplished that change over the next year.

OCALC is now making further improvements to the simplified processes in its propulsion division. It is automating the tracking of its inventory and testing the feasibility of introducing a flexible repair system into the compressor case repair cell.

Developing Modular Repair Centers

OCALC decided to introduce GT and cellular organization into the repair and overhaul of its engines for three reasons.

First, GT and cellular organization would help OCALC to meet schedules better for engine components. Schedules were missed because of the difficulty in tracking parts and sorting out their priorities when those parts were routed among various functional shops, such as grinding, machining, and welding. By introducing the cellular layout, OCALC believed that each cell's focus on, and responsibility for,

the repair of a part family would make that process simpler, better understood, more easily managed, and more effective in meeting schedules.

Second, GT and cellular organization would enable management to discover and correct problems in production. Under the functional layout, it was almost as difficult to trace the source of a problem as it was to correct it. A cellular organization would clearly identify the source of the problem, and the supervisor of the cell, who would have authority over each step of the process, could more readily correct it.

Third, the new organization would reduce the cost of operations. From its 1982 experience with engine work, OCALC believed substantial savings in equipment and floor space could be realized by converting the shop floor from a functional to a cellular layout.

Following GT and cellular principles, OCALC created 10 part-family cells (or Modular Repair Centers) in the propulsion division. Table 3-1 shows the resulting organization. Each of the 10 Modular Repair Centers performs the majority of the work for its part family, e.g., almost all of the work on nozzles is performed in the nozzle cell.

TABLE 3-1

OCALC MODULAR REPAIR CENTERS: PART-FAMILY CELLS IN PROPULSION DIVISION

Part-family cells	
Afterburner	Compressor rotor
Bearing housing	Gear box
Blades	Nozzles
Case	Seals
Combustion cans	Turbine rotor

However, some of the work on a part family is still performed in functional shops rather than in its cell. The reason for not incorporating this work in each of the cells is either cost (cells only employ this function infrequently) or safety (it may be too dangerous environmentally to decentralize the function). For example, plating is done in a separate plating shop outside the repair cells.

The Modular Repair Centers in the propulsion division of OCALC were developed in two steps.

First, potential part families were proposed on the basis of an analysis of the common processes by which parts were overhauled or repaired. To perform that analysis, past Work Control Documents were selected that reflected an average mix between new and old engines and light and heavy workloads. With that history, a code was used to break down the labor needed in each step of processing a part.

Second, to arrive at the precise number of Modular Repair Centers – as well as their configuration of labor, equipment, floor space, and conveyor design – OCALC engaged the University of Oklahoma to develop a simulation model. With that model, OCALC and the University of Oklahoma formulated the following assumptions and considerations to provide a solution for configuring the cells:

- The engine workload is 2,000 engines for a single-shift operation.
- The arrival rates of work control documents are fixed. (The demand rate cannot be altered to prevent bottlenecks.)
- The queuing of workload is a good indicator that bottlenecks are forming.
- A Modular Repair Center needs sufficient equipment and coverage of skills – four or more people in a particular skill in each cell – to be a bottleneck-free, efficient organization.
- Costs and environmental concerns need to be taken into account when establishing and configuring these cells.

Based on these assumptions and use of the simulation model, the equipment, labor, floor space, and conveyor design were configured into the 10 part-family cells shown in Table 3-1.

Benefits and Costs

Major benefits have resulted from the application of GT and cellular organization in the propulsion division at OCALC.[1] First, throughput times have been cut in half. Parts no longer have to be routed long distances to functional shops that previously performed the work. (Some parts had routings calculated in miles.) Thus, in-transit times have been greatly reduced. Also, because similar parts are being repaired within a cell, machines have to be set up less frequently, thereby significantly reducing the waiting times for machines.

Second, the efficiency of direct labor has increased more than 2 percent in the first year alone, and that increase translates into a savings of about $1.8 million. Productivity is expected to continue to increase. Savings that occurred in indirect labor have not been calculated.

Third, the same level of work requires less capital equipment. With cellular operation, the utilization of equipment generally is greater than that in the previous functional organization. At OCALC, 32 machines – worth $3.5 million – were made surplus to the propulsion division by this change in process technology, along with savings in floor space. Some of those machines were placed into inventory for future use; others have already been transferred to other uses.

Other benefits are expected from the OCALC cellular organization, but they have not yet been fully measured. For example, work-in-process inventories have probably been reduced because of reduced in-transit and waiting times. Furthermore, because of greater proficiency and quality-consciousness in each cell – stemming from working on a single part family and from the supervisor having responsibility for all the processes – the amount of scrap and rework is also expected to have declined significantly.

Performance measurement is shortchanged by the current accounting system, which does not provide useful incentives for operations. Currently, the accounting system focuses primarily on direct labor. That focus may have been suitable when

[1]The benefits are preliminary because OCALC has not fully revised its engineering standards since introducing the cellular organization. These benefits were cited by A. Ravindran, B. L. Foote, L. Leemis, and A. B. Badiru, "Analysis of Capacity Planning and Material Handling at Tinker Air Force Base," presented at the meetings of the *Operations Research Society of America*, Washington, DC, Apr 1988.

labor represented the main cost of operating the facility. Now, however, indirect labor, materials, inventories, and equipment account for most of the costs. Also, in the private sector, management thinking is shifting its focus from the utilization of resources to more-output-oriented measures of production, e.g., throughput time and reject rates, and the accounting system needs to provide such data as well [6]. OCALC's new inventory-tracking system will provide some of these new measures on a regular basis.

Finally, and of great importance, cellular organization has simplified OCALC's production and improved management's understanding of the process. With this improved understanding mobilization planning can be better accomplished. Also, simplification has led to a firm foundation for targeting automation and for controlling inventory and production, and is discussed in the following subsection.

The additive cost for planning and implementing the cellular organization in OCALC's propulsion division was under $3 million. That cost includes research, planning, moving equipment, and purchasing decentralized storage equipment – all representing a small fraction of the $73 million cost of recovering from the 1984 fire.

It is not often that so much can be obtained for so little. The propulsion division has been transformed into a cellular operation at a marginal cost of less than $3 million, and its *immediate, measurable* benefits total more than $5 million. What is more, those benefits (and others not yet measured) were obtained using less capital equipment than was previously used.

Next Steps

While the cellular organization simplified production in its propulsion division, OCALC still needs to obtain better control over inventory and production. It is working on an automated tracking system that will more easily account for, and greatly improve control of, inventory. In addition, the Air Force Logistics Command (AFLC) is pursuing the possibility of adopting MRP-II for scheduling production and for further controlling inventory. (For a technical discussion of the different kinds of automated systems for controlling inventory and production, see Appendix B.)

With the simplified, cellular process for maintaining and repairing engines at OCALC, some important follow-on capital investments have been undertaken. For example, OCALC has been able to introduce into each Modular Repair Center

nondestructive inspection equipment that is less complex and more focused on the individual parts than the equipment that had been used under the functional layout. Such simple, follow-on capital investment has been highly successful.[2]

A candidate for automation emerged from the Modular Repair Center for engine cases. The simplified, cellular operation for engine cases has made its workload sufficiently high, repetitive, and predictable to offer promise for an automated flexible system.

Equally important, the application of cellular organization has made it clear where automation is unlikely to pay off. It appears that the nonrepetitive nature of the workload in many of the Modular Repair Centers severely limits the extent of automation that can be successfully incorporated into those cells. Partial automation of some segments of the Modular Repair Centers seems much more beneficial than full automation of those cells.

Transferability to Other Air Logistics Centers

AFLC has designated the concept of Modular Repair Centers for possible transfer to other air logistics centers (ALCs). Beginning in mid-summer 1988, OCALC will make formal presentations to the other ALCs describing the benefits and costs of the cellular concept. After evaluating the potential costs and benefits, the other ALCs will be required to provide a full response as to whether they will adopt the Modular Repair Center concept. In the interim, OCALC has provided its simulation model to the other ALCs for consideration.

OCALC's experience with process-flow analysis is also transferable to the other ALCs. Those ALCs can then use this technique to formulate potential part families and the results can be tested with the simulation model.

OCALC introduced the Modular Repair Centers en masse because the 1984 fire interrupted production in the propulsion division. In contrast, the other ALCs will have to carefully phase in Modular Repair Centers so as not to disrupt production. In this regard, we present in the next section a discussion of how the Navy phased in its cellular operations to avoid disrupting production.

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[2]For a more general argument on successful automation going hand in hand with simplified production, see [7].

INDIANAPOLIS NAVAL AVIONICS CENTER

The Navy has also applied the concepts of GT and cellular organization, but primarily in manufacturing rather than in maintenance and repairs.

The Indianapolis Naval Avionics Center (NAC), Indiana, a manufacturing facility, began working with GT and cellular organization as early as 1976. The NAC staff identified GT and cellular organization as a basis for improving scheduling, reducing costs, assigning product-specific responsibility on the shop floor, and removing barriers to communication between workers and supervisors.

Indianapolis NAC created five part-family cells working with the principles of GT and cellular organization. To form part families for organizing production, the NAC staff analyzed the processes for manufacturing the entire range of parts and grouped parts together that underwent similar processes. Initially, management did not rearrange the shop floor into cells for those part families, but it did place the machines and operators that would have been in these cells under a single manager and worked as a cellular operation. Management wanted to see some of the benefits before committing itself to this process technology and to moving machines and physically rearranging the factory floor.

The results of this 3-month test are significant. Although the shop floor was not physically rearranged, the NAC realized a 33 percent improvement in average cycle time and a 6 percent reduction in actual direct-labor hours relative to standard direct-labor hours. In view of those benefits, management approved rearranging the shop floor along product family lines, and achieved even greater results with the physical creation of the cells.

There are two major applications of GT and cellular organization in the Naval Aviation Depots (NADEPs). First, the NADEPs have used GT to maintain a computerized record of part designs. These designs are especially helpful when an old part has to be remanufactured and its specifications are not available. In that case, the designs of similar parts can be helpful in providing such specifications and in process planning – avoiding time-consuming reverse engineering that otherwise would be required to establish the specifications anew.

Second, the NADEPs have used GT to create part families, which they have used in turn to form cellular operations in their manufacturing operations. (The

NADEPs manufacture critical spare and repair parts that cannot be purchased from contractors because of leadtime, availability, or cost considerations.)

NADEP NORFOLK

Developing Cellular Layout

In January 1981, personnel from NADEP Norfolk, Virginia, visited Indianapolis NAC to learn about its experience with GT and cellular organization of manufacturing. NADEP Norfolk was experiencing excessively long turnaround times in its machine shop, and based upon preliminary results, Indianapolis NAC had a solution to that problem. The NADEP Norfolk representatives came away from that meeting with the following key principles for establishing a cellular organization for their machine shop:

- Production-flow analysis should be used to establish part families for cellular operation
- Computer simulation is not necessary if the entire organization works closely together to develop the cells.
- The cellular operation should be implemented in discrete stages.

By analyzing the processes used for machining individual parts – some 300 machines, 30 of which are numerical control machines – 3 families of parts were formed; 1 for cylindrical-shaped parts, 1 for flat-surface parts, and 1 for large parts and rework.

The machine shop employed simple cutouts to consider potential layouts for these part families. Supervisors and workers worked closely together to arrive at a consensus, and they considered the following three issues.

First, the three cells would not be entirely self-contained. General-purpose shops were retained or established for heat-treating, plating, and sawing. The reasoning was that these functions were either performed too infrequently to be included in each of the three part-family cells or too hazardous to be operating in so many locations.

Second, the cells would be flexible to ensure a sufficiently high volume in each of the part families. Machines with wide capabilities were sought. If tradeoffs had to be made between the broad capability of a machine and the speed at which another

machine performed a particular job, the machine with breadth of capability was selected.

Third, more machines than operators would be present in each cell. Because of the variable nature of the work, all of the machines would not be operating at any one time. Workers would be cross-trained so that all skills would be available as needed.

From January 1982 through October 1983, NADEP Norfolk implemented cellular organization within its machine shop. Following the lessons of the Indianapolis NAC's experience, the reorganization took place in phases.

Phase I was a 90-day trial period to see whether GT had significant benefits before rearranging the machinery in the machine shop. Workers were assigned to each of the three supervisors and work was conducted along part-family lines. The test was highly successful: the repair status of parts was more easily tracked, and parts were no longer lost as before; days-in-process decreased; and communications between supervisors and workers improved. Consequently, management approved implementing the cellular concept.

Phase II consisted of a 4-month period to change the physical arrangement of the machine shop from a functional to a cellular layout. This long period for phasing in the new layout was adopted so that production would not be disrupted. In fact, no more than 1 day of production was lost on any machine during this phase-in period.

(Phase III, incorporating the cellular concept into the new Consolidated Machine Center, is still to come. The Consolidated Machine Center will house both manufacturing and repair operations, and it is scheduled for completion in about 3 years.)

Benefits and Costs

Implementing cellular organization in the existing NADEP Norfolk machine shop has already had major benefits. Before the cellular approach, production was consistently 2 or 3 weeks behind schedule. However, since beginning the cellular operation, schedules have been regularly met – reflecting reduced in-transit times between functional shops and reduced waiting for machines. Moreover, with the functional layout, the rejection rate was considerably above 5 percent; now it is about 2 percent. This improvement in quality performance is not surprising because

supervisors of cells are directly accountable for the quality of the products that are manufactured in their cells – a factor that did not exist in the functional layout.

Resource savings have been noted but not precisely measured. Such savings include lower inventories, higher productivity for direct labor, and 10 pieces of equipment (worth in excess of $1 million) transferred to other uses.

NADEP Norfolk indicated that it needs to change its accounting system to reflect some of the important measures of success for the cellular operation. On the input side, for example, inventories need to be tracked better. On the output side, NADEP Norfolk has been tracking reject rates but not throughput times.

The "out-of-pocket" costs for establishing the NADEP Norfolk cellular operation were quite modest. With the planning tools and experience already provided by Indianapolis NAC, the costs to NADEP Norfolk for planning the cells were quite low. Physical implementation costs were also low, approximately $60,000 to pour concrete, relocate 59 machines, install 3 new machines (already on order before the use of GT), and transfer 10 machines to other shops. Savings in direct labor and equipment have more than offset the costs of implementing the cellular operation.

Some costs have risen with the operation of the cells. Machine maintenance has increased because the utilization of equipment is higher under the cellular approach. Training costs have also increased because workers have to be cross-trained in more than one skill to avoid labor-skill bottlenecks in the cells.

Transferability

Personnel at the machine shop at NADEP Norfolk believe the cellular approach is transferable to any production characterized by complex routings between shops, long setup times for machines, and the use of multiple machines of the same kind. Using those criteria, they believe that a cellular operation would be highly beneficial in repair as well as in manufacturing at NADEP Norfolk. The sheet metal shop, landing gear shop, the engine division, and wing shop were cited as promising applications.

Some work has begun to extend the cellular concept to these areas at NADEP Norfolk. Temporary cells have already operated in the landing gear shop with

considerable success. Moreover, machine shop personnel are working with personnel in maintenance and repair to embrace cellular organization in the new Consolidated Machine Shop. This has met with partial success thus far.

OTHER NAVY EXAMPLES

This process technology is also spreading to other activities in the Navy. Mare Island Naval Shipyard, Vallejo, California, is working with the principles of GT and cellular organization for manufacturing in its machine shop. Management plans to begin implementing this approach later this year and to complete it by the end of 1989. A manager of the shipyard has stated: "Manufacturing technology tools currently available (GT and cellular organization) [are expected to] make it possible to standardize the manufacturing process for a significant percentage of work moving through a job shop, facilitating improvement and optimization of machine utilization, shop routing and fixturing" [8].

Under the Rapid Acquisition of Manufactured Parts (RAMP) project, the Navy Supply Systems Command is beginning to work with GT, cellular organization, and flexible manufacturing systems to improve the turnaround time for manufacturing small mechanical parts and printed wire assemblies. Initially that effort will focus on some 3,000 parts, and the test sites for this work will be Charleston Naval Shipyard, South Carolina, and Indianapolis NAC. The project could lead to a Navy-wide system for GT, and that will facilitate all Navy industrial activities' efforts to simplify their production.

CHAPTER 4

LESSONS LEARNED FROM THE PRIVATE SECTOR

The lessons learned from the private sector verify the modernization strategy presented in this report: simplify production first, then computerize the control of inventory and production as needed, and automate production as appropriate.

Invariably, the companies reviewed subscribe to a step-by-step procedure for introducing technology into manufacturing and repair. Repeatedly, we were told that the greatest modernization mistake that can be made is to apply computerization and automation before reviewing and simplifying processes. Several companies even said that they had made costly mistakes by prematurely applying high technology to complex, poorly understood processes.

In this chapter, we look at specific lessons learned from a major airline in its maintenance and repair of commercial aircraft and from a major aircraft engine manufacturer in technology introduction and in its job-shop work. Then, we look at general lessons learned by others in the private sector on modernization strategies.

MAJOR AIRLINE

We visited with a major airline to understand its approach to modernization of the maintenance and repair of commercial aircraft. The key lesson learned was that responsiveness in production can be very high when processes and workload are simplified and controlled. Below, we discuss the steps this company has taken to achieve such simplification and control – steps that have helped reduce the turnaround time for aircraft engines to less than 30 days with very little high-technology capital investment and with no increase in inventory levels.

Control and Simplification

The airline took three major steps to control the workload entering depot maintenance and thereby reduce uncertainty. First, it created five discrete aircraft depot maintenance work packages. One for detection of corrosion, one for structural integrity, and three for gradations of overhaul. Each work package is triggered by a

threshold of flying hours – taken from analysis of historical flight data – and, therefore, is predictable. By having so many well-defined work packages, variation in the content of the work is reduced.

Second, it developed historical likelihoods of the need for replacement or repair of individual components. These replacement and occurrence factors are calculated at each flying-hour threshold. With this information, individual workload-content packages are prepared approximately 10 days before induction of the aircraft and parts are made available, as needed, at that time.

Third, it integrated its functions of maintenance and supply, giving the production planner control over workload generation. The production planner for aircraft engines, for instance, is also the engine Inventory Control Point. This dual responsibility enables him to make the necessary tradeoffs between keeping inventory levels low – by quicker repair of failed items – and keeping the shop floor workload steady and balanced by delaying or hastening workload induction. In contrast, in DoD these functions are usually separate and it is difficult to devise balanced incentives for depot production managers because they are not the inventory managers.

The airline has also pursued production simplification. As a result of its recent expansion, its depots around the country are now planning to specialize in different workloads. This specialization will be based on part families, which will help to simplify production, as it does in a cellular operation; that is, supervisors and workers in each locale will focus on a narrow set of products, and thus, their responsiveness and quality of production will improve even more.

Simplification is supported by performance measures. Careful records are kept of throughput times, removal rates of parts, and rejection rates. If throughput times vary by as much as a day, action is taken to diagnose and correct the problem.

Production and Inventory Control

The airline also developed its own computerized system for controlling production and inventory, a heavily modified version of Material Requirement Planning. The off-the-shelf systems available for manufacturing could not satisfy the more complex requirements of maintenance and repair.

This system generates daily schedules for production based on what items are predicted to be most needed over the next 5 days. It incorporates demand-side considerations very well: expected inductions of aircraft, anticipated rates that parts will be removed, and likelihood of repairs. It also keeps a 24-hour record of the inventories of all parts, some by serial number. However, the availability of equipment and labor on the shop floor to accomplish the work is not explicitly taken into account.

In effect, this system assumes that there is an infinite capacity on the shop floor to accomplish the work. As a result, maintenance planners have to override the work schedules indicated by the computer system when sufficient resources are not available to meet those demands. Thus, maintenance planners impose priorities on the work to reflect what must be done now, what can be delayed until later, and what is necessary to keep production running smoothly. The computer system tracks repair times on both standard and nonstandard repairs to help planners make such choices.

With planners working closely with the computer system in this way, daily production schedules are met and inventories are kept to a minimum.

MAJOR ENGINE MANUFACTURER

We visited a major manufacturer of aircraft engines to understand how it has introduced technology into its operations and how it operates a low-volume job shop for developmental items. It has a modernization strategy that includes simplification of production, shop-floor control, and automation.

Simplification of Production

This firm has three principles for simplification of production:

- Apply group technology (GT) to create part families as the basis for organizing production.
- Specialize production by geographical location among factories or by cells within a factory on the basis of part families.
- Utilize off-the-shelf simulation packages to explore the dynamics of production processes, to pinpoint potential problems, and to focus attention on where improvements can be made.

These three principles have been applied to the manufacture of aircraft engines, and they are covered below, in turn.

Group Technology

This engine manufacturer uses GT to form part families. They are formed by analyzing the process flows that individual parts follow and then grouping those parts that follow like processes. The part families are then used as a basis for organizing production in manufacturing cells. This technique for forming part families is called Production Flow Analysis (PFA).

This firm also tried to use another technique, classification and coding, for forming part families. Classification and coding uses the physical characteristics of parts (e.g., chemical composition, geometry, size) to group parts into families. However, it found this technique to be unwieldy for the large variety of parts it manufactures and to require the cooperation of too many people. In contrast, this technique was successfully used for tools and fixtures. In this smaller universe, classification and coding resulted in eliminating duplicative fixtures and speeding the design and manufacture of new fixtures. (Appendix A discusses these techniques for applying GT in greater detail.)

These results are also consistent with the experience of OCALC and NADEP Norfolk (described in Chapter 3) in that part families were created using PFA. Also, for an existing operation, it is much cheaper to form part families with PFA than with classification and coding.

Organization of Shop Floor

The engine manufacturer has organized its production around part families at two levels: First, for a given factory, cells are dedicated to the production of particular part families. Second, specific factories are assigned different part families.

In individual factories, dedicated cells have been formed to manufacture particular part families. For example, almost all of the operations necessary to manufacture nickel-winged disks are performed in one cell. Major benefits resulted from this cellular organization. Rework and repair were reduced by more than 40 percent over a 3-year period, and the quality of production improved as did the turnaround times. The cost of planning and implementing the cellular operation was low, and the cost for planning and moving machines was modest. At the same

time, by converting the shop floor from a functional to a cellular organization, the manufacturer realized efficiencies in the number and use of machines as well as in floor space.

At a higher level, the engine manufacturer simplified the process by having different factories specialize in different product families. For example, one of its plants specializes in the manufacture of blades and vanes, while another plant focuses on the manufacture of compressor cases. Each plant has realized the benefits of simplified production (quicker turnaround times and improved quality) by concentrating on a narrow set of products and processes.

Simulation of Processes

This aircraft engine manufacturer also has found that existing processes can be improved if they are better understood. To understand them better, it uses off-the-shelf simulation programs to study their dynamics. Using simulation the processes are "shocked" with different scenarios to explore where problems might arise in actual production.

Problems with a process might arise from a variety of causes. There may be bottlenecks in certain resources in some situations and the effectiveness of the process might deteriorate under others. By performing extensive simulations off-line, the company can detect these situations before they arise in actual production.

Processes may be changed or simplified to prevent such problems from arising in actual production. The simulation program is used to study these possible changes in the "laboratory" to avoid making costly mistakes on the shop floor.

Inventory and Production Control

This aircraft engine manufacturer has decided to build its own computer system for the control of production and inventory. The system will be used in its developmental job shop. (This developmental job shop helps the transition from engineering to production. It employs more than 1,000 people to work on prototype processes and parts.)

This group had worked with MRP-II, but believes that it does not have the flexibility to capture the essence of its job-shop operations.

It also investigated using Optimized Production Technology (OPT). Although in agreement with the central idea of OPT – that production should be geared to the output of the entire system and bottlenecks should be intensively managed – the manufacturer did not acquire the system because its software is proprietary and too expensive. (Appendix B compares OPT with MRP-II.)

In building its own system, this company is developing artificial intelligence, rule-based systems that mimic each of the informal, local-rule systems now used in the individual shops for controlling inventory and production. Then, using some of the concepts of OPT, it will work on optimizing production and inventory for its entire operation.

Automation

This major aircraft engine manufacturer has a formal strategy for introducing automation into production. The strategy, formulated by its developmental group, has the following key principles:

1. Automation should be used to assist the workers to do their jobs more efficiently or better, not to replace workers *per se*. Workers, not machines, make suggestions for continuous improvement, and, therefore, labor is the primary asset of the organization.

2. New technologies and processes should be introduced into the factory on a pilot basis to ensure a smooth, effective transition to the shop floor. A slow, incremental approach will avoid costly mistakes on the shop floor.

3. Knowledgeable engineers, and others who procure technology, should be located throughout the plant. Such expertise avoids buying technology that has unnecessary, complex "bells and whistles" – a source of costly mistakes.

4. The process should first be simplified and then the technology should be automated and integrated. Simplification must be primary.

5. New processes and technologies should be developed in discrete steps that include performing tests and validations as well as creating prototypes in the laboratory.

6. Feedback loops from the users of the products to the designers of those products should be developed. In that way, future design will better take into account the needs of the users.

These principles were developed after this company suffered some painful lessons. For example, it had put in a state-of-the-art, fully automated factory in one of its plants without first simplifying the process [Principle 4] and without incremental testing of that automation [Principles 2 and 5]. As a result, that plant is efficiently performing some less-than-smart processes. This company has concluded that automation should be introduced only after first simplifying processes on the shop floor.

OTHER COMPANIES

Overview

Other companies have confirmed the lessons detailed above:

- Another major airline recently stopped development of an automated production and inventory control system for its maintenance operation, so that it could first review and simplify its processes. That firm is also reviewing its current performance measures and trying to develop new ones that will give better, more balanced, incentives.
- Another major manufacturer discovered that all the benefits expected from a massive automation project were achieved by simplifying production using cellular manufacturing. The capital investment for new machinery was largely unnecessary.
- An aircraft repair firm decided classification and coding was impractical because different people coded the same parts differently.

In addition, consulting firms are beginning to adopt this strategy. In response to a presentation of an earlier version of our modernization strategy for DoD maintenance depots, representatives of a number of firms agreed with the general strategy [9]. They also were skeptical about using MRP-II in a repair environment. They indicated that this system was designed for manufacturing and cannot easily be adapted to the more complex environment of maintenance and repairs (see Appendix B). Other approaches are needed.

Accounting and Performance Measures

Another area in which the private sector agrees new approaches are needed is accounting and performance measures.

Accounting systems have not kept abreast of the changing technologies that have been applied on the shop floor. Traditional accounting systems in the private sector focus on direct labor, and assume that all other resources are small and in fixed proportion to direct labor. That assumption is a mistake in today's rapidly changing technological environment. Overhead cost is now 20 times greater than direct labor cost [10]. Rapid technological change has also made the relationship between direct labor and other resources anything but fixed.

Process simplification needs to be accompanied by accounting system simplification. Some companies are starting to do this. As processes are simplified and manufacturing cells are created, some overhead personnel are eliminated – parts expediters, for example – and others are being assigned directly to a cell. Similarly, complex reports and computer systems may be eliminated along with their associated costs and personnel. Costing individual parts is also simplified. Because all parts of a given type are made in one cell, the cost for a part is simply the costs for the cell for a period divided by the number of parts made in that period. Further, if inventory is reduced and flow days minimized, inventory accounting is greatly simplified, sometimes to the point of charging it to the factory when it enters and to the product when it leaves, with no intermediate charges. Finally, the remaining overhead can be allocated by flow days for each product rather than by direct labor hours. That approach is realistic in that overhead tends to be concerned with keeping track of work in process and dealing with complexity; products with short flow times have minimized those problems.

Associated with simplified accounting systems are better performance measures. Flow times for each product, for example, need to be known as does the occurrence of rework brought about by rejections – which can result in abnormal routings and material usage. Without these performance measures, the costs of products cannot be known, the benefits of simplification cannot be quantified, and the proper incentives for simplification cannot be created. Private-sector firms are focusing on these measures as they pursue simplification.

The lesson for DoD depots is that their accounting systems will need to be changed and that performance measures need to be developed.

The unmistakable lesson from the private sector is: simplify first. That approach is the key to bringing accounting systems up to date and is at the heart of the successful technological strategies being used in the private sector.

GLOSSARY

AFLC	=	Air Force Logistics Command
ALCs	=	air logistics centers
CIM	=	Computer Integrated Manufacturing
CIMS	=	Computer Integrated Manufacturing Systems
FMC	=	Flexible Manufacturing Cell
FMS	=	Foreign Military Sales
GT	=	Group Technology
JIT	=	Just In Time
MRP	=	Material Requirement Planning
MRP-II	=	Manufacturing Resource Planning
NAC	=	Naval Avionics Center
NADEPs	=	Naval Aviation Depots
OCALC	=	Oklahoma City Air Logistics Center
OPT	=	Optimized Production Technology
PFA	=	Production Flow Analysis
RAMP	=	Rapid Acquisition of Manufactured Parts
REPTECH '88	=	U.S. Air Force Repair Technology Conference 1988
SPC	=	Statistical Process Control
TQM	=	Total Quality Management

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APPENDIX A

GROUP TECHNOLOGY AND CELLULAR ORGANIZATION

INTRODUCTION

In this appendix, we explain the concept of Group Technology (GT) and the theory of cellular organization of production. We also briefly discuss the benefits of GT and cellular organization for automation and for Total Quality Management (TQM). A bibliography of key publications is presented at the end of the appendix.

GT has taken root in manufacturing in the United States. It has been implemented in many large manufacturing corporations, including General Electric Corporation, Black & Decker Corporation, Caterpillar Inc., and Lockheed Corporation. Also, as indicated in Chapters 3 and 4 in the main text, it has spread to some of DoD maintenance depots and to repair operations in the private sector.

GROUP TECHNOLOGY

Definition

GT was developed to increase efficiency by exploiting the similarities of manufactured items. It can be applied throughout the entire manufacturing cycle of design, purchasing, process planning, production planning, and production.

The basic group in GT is a family of parts ("part family"). A part family consists of parts that are similar either in physical properties (e.g., size, chemical composition) or in the processes that they undergo (e.g., turning, grinding). These part families can be exploited in the design phase. For example, designing a part from scratch can be avoided by first identifying what part family the part would belong to, and then either substituting the design of a part that already exists in the family, or modifying the design of a related part in the family.

We focus on GT in production and how it can be extended to job-shop work in maintenance and repair. In the production phase, the formation of part families enables certain labor and equipment to be placed in a single area and dedicated to the production of a single part family; that procedure is referred to as cellular organization of production. Such organization results in substantial benefits for the

production process. (Those benefits are discussed, in detail, in the section on Cellular Production in this appendix.)

Forming Part Families

Three main methods have been used to form part families: Production Flow Analysis (PFA), which provides information on the processes, machines, tooling, and fixtures necessary for the production of a part; a classification and coding system that provides details on the physical characteristics of each part (e.g., shape, dimension, chemistry, and function); and a hybrid classification and coding system that combines the information from PFA with the information on the physical dimensions of the parts. (This hybrid system often works with a code more than 30 digits long and requires considerable computer power for its execution.)

PFA was the first method used for forming part families. With PFA, each part is followed through its sequence of processing on machines and codes are assigned to represent that processing flow. For example, a part may first be worked on a lathe (assigned a code of 1), then worked on a stamping machine (assigned a code of 2), and finally on two milling machines (assigned a code of 3). For that part, processing is represented by the code 123. In contrast, another part may be worked on by the stamping machine, followed by a milling machine, and then by metal cutting (assigned a code of 4). Thus, this part would be assigned a code of 234 to represent its processing. Those two parts have substantial overlap in processing – 123 versus 234 – and could be members of a (wider) part family.

In a basic classification and coding system the physical characteristics of each part are the focus of the part family coding, and those codes are hierarchical. For example, consider two steel parts, coded by 1 to represent that fact, both with a high carbon content (also coded 1). Then the carbon-steel content of both of those parts is represented by the code 11. The differences in the two parts occur in the next physical characteristic considered: the first part is of high grade steel and is assigned a code of 1, and the other is of medium grade steel and is assigned a code of 2. Stringing together the codes to represent these physical characteristics, the first part is coded 111, while the second is coded 112. The similarities in the physical characteristics of these two parts – carbon steel – and the differences in their grades are taken into account in forming part families.

The hybrid system combines the coding of the physical characteristics of the parts to the coding of the processes. From the two examples above, the first part would have a characteristic-processing code of 111–123, while the second part would have the hybrid code of 112–234. In fact, codes of 30 or more digits are used in such hybrid systems.

Most practitioners feel that PFA is easier to learn and utilize than the classification and coding schemes that involve focusing on the physical characteristics of the parts, particularly when the benefits sought are in the production phase rather than in the design phase. Experience in the private sector and DoD maintenance depots bears this out (see Chapters 3 and 4).

Part families can be used to change the focus of production and the layout on the shop floor. This is explained further in the next section.

CELLULAR PRODUCTION

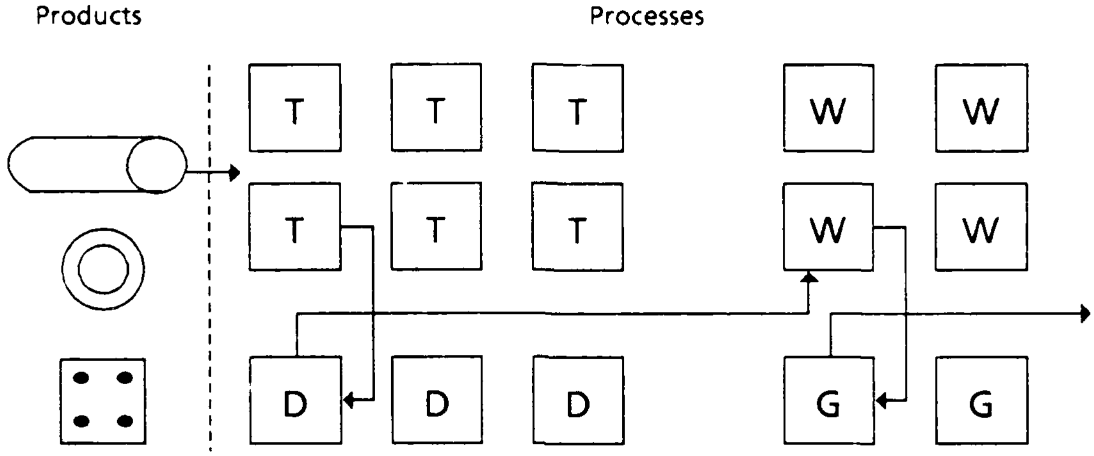
Development

A hypothetical job shop in maintenance and repair is depicted in Figure A-1. The layout of this shop is functionally organized: six turning machines in one location, three drilling machines in another location, four welding machines in yet another location, and two grinding machines in a final location. Each of these functional shops has a supervisor in charge.

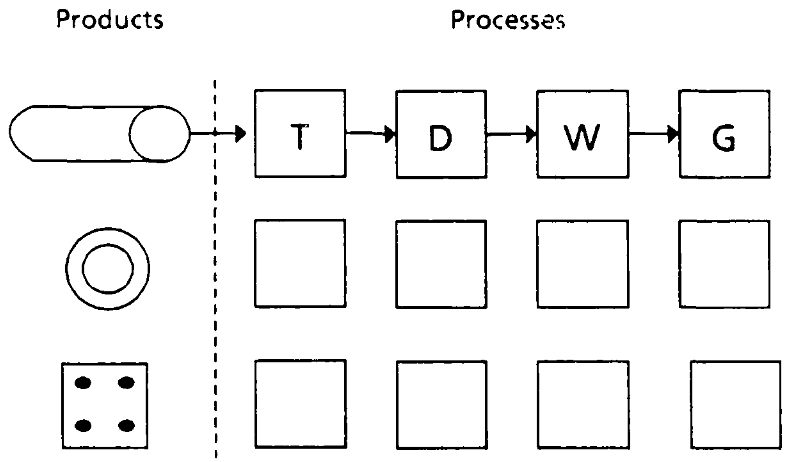
Now, consider one of the three parts – the cylindrical part – and its routing through these functional shops. In Figure A-1(a), the cylindrical part is first routed to an available machine in the Turning Shop, then to the Drilling Shop, the Welding Shop, and finally the Grinding Shop. The cylindrical part is routed as an individual part, possibly for long distances – and the time spent moving it through the shops and waiting for the setup on machines in those shops is excessively long. During this time the cylindrical part is counted as work-in-process inventory. Also, no single supervisor is in charge of the quality of the cylindrical product *per se* making it difficult to determine the source of any problem that may arise, and how to make corrections and improvements on that part.

Now suppose PFA is used to form a repair cell for the cylindrical part. That is, suppose a turning machine, a drilling machine, a welding machine, and a grinding machine are physically placed together and dedicated to producing cylindrical parts.

Let us call this the cylindrical part cell [see Figure A-1(b)]. That cell is headed by a single supervisor responsible for the quality of the repairs on all cylindrical parts. That supervisor works closely with the operators of the different machines involved in the repair of the cylindrical part – fostering immediate feedback from the supervisor to the workers on the quality of the work and encouraging workers' suggestions for improvement.



(a) Functional Layout



(b) Cellular Layout

Note: T = turning; D = drilling; W = welding; G = grinding

FIG A-1. COMPARISON OF FUNCTIONAL AND CELLULAR LAYOUT

In the cylindrical part cell, the cylinder no longer travels long distances as in the functional layout. This shorter routing makes it easier to track the part's repair status and to focus attention on priority parts. Equally important, the throughput time for repairing the cylindrical part is lowered substantially and work-in-process inventory is reduced appreciably as well.

Conditions for Success

In general, several conditions are necessary for GT and cellular organization to result in major improvements to DoD maintenance depots:

1. The existing functional organization must be characterized by relatively complex routings of the products to be overhauled, repaired, modified, or rebuilt.

2. Each cell must have a sufficient volume of parts to warrant the dedication of equipment, labor, floor space, and other resources.

3. In the existing functional organization, setup times on machines should be a significant fraction of the total time on machines.

Condition 1 applies to many products in many DoD maintenance depots. Complex routings pervade their operations. Following a part physically around the shop floor or following the routings of that part on work-control documents easily demonstrates this point.

Condition 2 is frequently met in DoD maintenance depots. Part families often can be taken directly from the outcome of PFA to yield sufficiently high volumes of production. However, sometimes these part families are merged to somewhat broader groupings to achieve sufficiently higher volumes in production or to obtain needed redundancies in labor skills and in machines. Simulation models or manual methods have been used to configure the resources in the cells.

Condition 3, long setup times, is also prevalent in DoD maintenance depots that are characterized by functional layouts. By definition, the job-shop work in the depots involves small batches of work which, in turn, lead to frequent setups on machines.

Because these conditions apply in many operations in DoD maintenance depots, the cellular organization of the shop floor is already resulting in major benefits. As described above, the immediate benefits from the cellular organization

include quicker turnaround time on repairs, decreased work-in-process inventories, and increased productivity of direct labor.

GT and cellular organization of the shop floor offer significant "downstream" benefits, and those benefits are discussed briefly in the following subsection.

ADDITIONAL BENEFITS

Automation

Analysis with GT will help improve the ability to use robotics in a job shop. Usually, a robotic application focuses on one or a few specific parts, and if the volumes are high enough, a robot can be specified and used successfully on repetitive or tedious tasks. Using GT, some of the preliminary parts under consideration for the robotic application can be combined with other parts that undergo similar processes. In this way, GT broadens the base of parts for the robotic application and can lead to a robotic application that will be economically viable.

Also, the ability of GT to define part families can help delineate what parts should be produced in a Flexible Manufacturing Cell (FMC). (An FMC consists of a series of machine tools that are linked together with automated handling of materials.) The grouping of parts can be evaluated for their characteristics, annual volume, accuracy of data, and other factors that pertain to the FMC. Developing specifications for the FMC is actually an extension of developing the (nonautomated) cellular layout described above.

Finally, GT can be used to reduce the complexity of routings and bills of materials, which is important for implementing automated production and inventory control. (This is explained more fully in Appendix B.)

Total Quality Management

Creation of cellular organizations in DoD maintenance depots will foster many of the features of TQM. The main linkages between cellular organization and TQM briefly are discussed here.

TQM requires that human resources be effectively utilized, continuous improvements be a goal, customer satisfaction be the ultimate goal, and quality- and cost-consciousness pervade the entire organization. The process improvement of the cellular organization is consistent with many of these requirements.

The managerial advantages of a cellular organization in DoD maintenance depots are evident. The cellular operations assign clear responsibility and authority for producing the product efficiently and with high quality. The supervisor of a cell has authority over the entire stream of processing for the part family in that cell, including the machines and operators needed for such processing. The workers are familiar with what they are working on and their immediate "customer" is the next worker in the same cell; thus, they have immediate feedback on the quality of their products. Communications between workers and the supervisor are direct, and immediate, so that quality becomes "everyone's business." Furthermore, costs of the product are focused upon in the cellular environment – e.g., reducing scrap and rework.

By contrast, in a functional layout of the shop floor, the manager of a functional shop is responsible only for an isolated operation on a part – previous and succeeding operations are under the control of other managers. Also, an operator in a single shop works on a batch of parts, and that batch moves into storage or queues that extend over many days – making it difficult to obtain meaningful feedback on problems. The result is delayed feedback, if any, between the different managers and workers on problems in production, let alone on making improvements. Quality is checked by a special inspection function after production is completed – a direct violation of one of the principles of TQM.

To foster continuous improvements on the shop floor, TQM advocates the use of Statistical Process Control (SPC). SPC is used to quantitatively determine whether a fixed process is stable or out of control in production and to help bring about improvements in that fixed process. SPC is difficult, if not impossible, to accomplish in the current functional environment of DoD maintenance depots but may be possible in a cellular layout of those depots.

In the typical job-shop environment, however, SPC is very difficult to apply because processes are constantly in flux. In such an environment, a product will be assigned to the machine that is available at any specific time. Tooling and fixturing are also assigned randomly; whatever is available in the tool crib will be used for the particular job. The next time the same type of job is faced, it may or may not be done with the same machine, operator, tooling, or fixtures. As a result, it is difficult to measure variations in production with a given process when the process itself is changing.

In the cellular organization, the methodology of SPC has a better chance of being applied successfully. Machines are dedicated to a cell that focuses on a particular part family so the same machine, tooling, fixtures, and operator repeatedly perform the same processes on the same parts. Such regularity in production allows a history on each product's processing – a necessary condition for the application of SPC.

A cellular organization is an important basis for improving the processes in DoD maintenance depots. Cellular organization is a subset of the entire TQM philosophy (see Deming and Imai in bibliography) and, as a result, other TQM principles can be built more readily upon cellularly organized production.

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APPENDIX B

INVENTORY AND PRODUCTION CONTROL

INTRODUCTION

In this appendix, we examine the underpinnings of two important automated systems that have been used in the private sector for controlling inventory and production. First, we discuss Material Requirement Planning (MRP) and its extension, Manufacturing Resource Planning (MRP-II). Second, we review Optimized Production Technology (OPT) – a recent development in this area. Finally, we compare MRP-II and OPT to help potential users understand the major differences between them. A bibliography of key publications is presented at the end of the appendix.

MRP AND MRP-II

MRP is a set of techniques used to make recommendations for ordering materials to replenish depleted stocks and for scheduling production. It establishes and maintains accurate due dates on ordering materials and can be employed to reschedule open orders when due dates for production and need dates for materials are not properly synchronized.

MRP has evolved into a broader tool, MRP-II. MRP-II does everything that MRP does, performs financial planning, and has the capability to play "what if" games. The additional capabilities are important tools for assessing and addressing change. Because MRP-II creates an integrated database for the entire organization, it can unify the financial reports of an organization – such as its business plan, shipping budget, and inventory projections, to name a few. We are interested here in the capability of the MRP-II system insofar as it deals with scheduling production and ordering and rescheduling materials.

The primary objective of MRP and MRP-II is to determine the quantity and timing of materials needed for manufacturing products. Such planning has three basic aspects: development of the master production schedule, determination of the

materials required to meet the schedule, and estimation of workloads by work centers.

The master production schedule shows the expected production, usually on a weekly basis. This schedule is established through the interplay of demand management and resource planning. Demand management helps define what manufacturing is needed to meet customer requests, while resource planning is supposed to help define what resources are needed to schedule work and to produce output from week to week. However, with these systems, resource limits are only partially accounted for in scheduling production. MRP and MRP-II do not explicitly address the requirements for long-term capacity, nor do they fully address all of the requirements for variable resources.[1]

MRP and MRP-II focus directly on requirements for material but not on other resource requirements. For material, the master production plan is "exploded" through the bill of materials to find the gross time-phased requirement for material. To find the net requirement for material, material already on hand or on order from a vendor is subtracted from the gross requirement. Planned order releases are then calculated to meet that net requirement.

The calculation of planned order releases normally involves two simplifying assumptions: constant leadtimes and constant batch sizes.[2] Those assumptions permit "backward scheduling," i.e., order releases are "backed up" from the due date by their leadtime. These backward-scheduled order releases for all products are then summed up by shop to see whether they are feasible in terms of the available labor hours in those shops. If they are, the schedule is used; if they are not and if no other source of supply or other solution can be found, the master schedule is changed. This iteration is called "rough-cut capacity planning."

Neither MRP nor MRP-II explicitly deals with possible bottlenecks in labor and equipment. Instead, these algorithms provide for some arbitrary slack in scheduling

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[1]Variable resources – labor and materials – are important for making decisions about week-to-week schedules. Such short-run decisions determine how much of the plant's capacity will be utilized. The capacity of the operation itself – a longer run consideration – is set by the physical size of the facility, the equipment in that plant, and the technology available. The capacity of the plant sets the limit on the production that can be achieved.

[2]For the computed master production schedule, leadtimes and batch sizes are constant. It is possible – and some companies have done so – to vary leadtimes and batch sizes from one solution to another. However, this process is highly computer-intensive and cumbersome.

to meet short-run scarcities in those resources if such shortages should arise – normally set in the range of 80 to 95 percent of the setup and machine-running time. In a period of reasonable availability, the assumption that labor and equipment would not be very constraining might be tenable. The simplifying assumptions that the size of the batches as well as the setup and machine-running times (leadtimes) are constant are consistent with this assumption of nonconstraining resources.

However, in a period of scarce labor and equipment – as in the current expansion phase of the U.S. business cycle – the assumption of nonconstraining labor and equipment has led to major disappointments in the execution of MRP and MRP-II in the private sector. Under constrained resources, batch sizes tend to be reduced and leadtimes tend to be increased. Ideally, batch sizes as well as leadtimes should be a function of available resources and scheduling and, therefore, should be part of any optimal solution.

In addition to this lack of a comprehensive focus on resources, MRP and MRP-II have requirements for their successful use that have caused problems on the shop floor. Both require 95 percent or better data accuracy on routings and bills of materials – accuracy difficult to achieve, particularly in a job shop. MRP-II is also a very rigid system in its requirements for data entry and in its material-control discipline, this rigidity may be a major drawback in a nonrepetitive repair environment.

Further, in the case of repairing or remanufacturing, MRP II needs to be customized. It was created for a manufacturing environment and, therefore, addresses only two functions at a time, typically fabrication and assembly. Without modification, it cannot also address the additional functions of diagnosis, disassembly, and repair needed in the depots. (By the same token, MRP systems assume only two sources of supply for components, purchase and manufacture. In remanufacturing, parts can also come from usable returns, repaired components, and "backrobbing" from other end items.) Many more capabilities have to be added to cope with the additional complexity of the repair environment.

This complexity of the repair environment can be illustrated by looking at what happens to the bill of materials for an item entering the depot. Items that enter a repair facility may be serviceable as is, in need of repair, or not reparable. Because both MRP and MRP-II were developed for manufacturing, they do not provide for those alternatives. Without modification, these systems would assume that all items

entering the facility need repair and would order the full bill of materiels for that purpose. To obtain accurate estimates of bills of materials for remanufacturing, the added dimensions of remanufacturing must be incorporated into any system for controlling inventory and production and replacement factors and occurrence factors must be estimated.[3]

A great deal has been published about why MRP and MRP-II systems have failed so often in manufacturing. Some attribute it to complex bills of materials and routings that are too difficult to document with at least 95 percent accuracy. Others attribute it to personnel who are not sophisticated enough to be assigned the task of implementing and working with complex computer systems.[4] Both of these problems experienced in the manufacturing environment will be even more pronounced in a repair environment because of its complexity and uncertainty.

OPTIMIZED PRODUCTION TECHNOLOGY

The primary stated objective of OPT is to minimize throughput time. Flow of production, not the utilization of capacity, is emphasized. Because throughput is often hampered by bottleneck resources in a few work centers, OPT focuses on maximizing production in those bottlenecks. This concept of the bottleneck has a long history in the economic and operations research literature.

To maximize production in bottleneck operations, OPT normally places work-in-process buffers in front of bottlenecks and in back of those bottlenecks that become inputs to other operations. Also, the bottleneck operations receive large batch sizes to reduce the relative time spent in setup of machines, while the nonbottleneck operations receive smaller batches to reduce inventory. Output of the operation as a whole is the focus of OPT, not the local optimization of each of its constituent operations.

OPT reportedly has its foundation in linear programming. The details of the approach are not known for certain because the algorithm is proprietary and kept

[3]Replacement and occurrence factors are dynamic and need to be changed frequently. These factors have been shown to be a function of time in use, age of the parts, and other conditions. As a result, these factors may vary considerably within a year, and the use of static measures may cause considerable problems on the shop floor. Dynamic measures may be obtained by either frequently updating historically derived averages or by working with statistically derived models that describe how these factors change.

[4]Still others believe that these systems have failed because of resistance to change and lack of organizational commitment.

from the user. However, we believe that the algorithm has an objective function that relates to throughput time. Also, the user sets some three dozen parameters to define demand and constraints. The constraints include policies of delivery and customer service, maximum outputs from labor, equipment, and on-hand inventories.

As part of a typical linear programming solution, labor, equipment, and materials in each work center are classified as "scarce" or "abundant." Such a classification of resources depends upon whether the linear-programming solution "consumes" the entire available amount of the associated resource. If the optimal solution fully consumes a resource, then that resource is indicated as scarce. In contrast, if the solution only partially consumes a resource, then that resource is indicated as abundant. By definition, bottleneck operations have one or more scarce resources while nonbottleneck operations have only abundant resources.

Once the bottleneck operations are identified, OPT requires more information on those bottlenecks. Some typical questions are: Are the data correct? Are the time standards accurate? Are additional resources available? Can alternate routings be used for some items? As changes are made, additional "runs" of the linear programming model are required to test for remaining bottlenecks. When the iterations are completed, the master production schedule is modified according to what the program has determined can be done. (If there are no bottlenecks, OPT operates very much like MRP.)

OPT schedules bottleneck and nonbottleneck operations at different levels of detail. For the bottleneck operations, OPT provides a detailed, hour-by-hour, "finite" schedule. In contrast, the nonbottleneck operations require much less precision – less detailed than in MRP.

Some of the managerial implications of OPT are quite fundamental to the way the organization operates. The traditional cost-accounting rules focus on direct labor and, in effect, require that all employees be working continuously. However, according to the principle of OPT, if people working on nonbottleneck resources are utilized continuously, all that they accomplish is the accumulation of excess work-in-process inventories. OPT maintains that it is acceptable not to do work continuously so long as the loss of that production does not hamper throughput. That contention is consistent with the Japanese belief that nonworking time is not wasted if that time

is used to increase quality, to improve industrial engineering, or to further train labor.

Managers may also have to change other practices with OPT. For example, lunch hours may need to be staggered so that bottleneck machines "run" constantly. Cost-accounting systems may need to be revamped to reflect operating and inventory costs that are consistent with OPT's system-wide view of operations.

As of 1985, about 100 companies worldwide have installed OPT. Most of these companies were facing serious problems with leadtimes or with bottlenecks. Each had a very large variety of products that required processing in as few as 5 and as many as 40 centers. The consultants that worked with these companies imposed a set of contract rules on top executives to make procedural, cost-accounting, and work-method changes. With such constraints imposed, users seem to be reasonably happy with the results.

General Electric's engine plant in North Carolina is a case in point. Within 3 months, it installed OPT and began generating efficient production schedules. The results have been a 30 percent reduction in its work in progress and a reduction in inventories from a 140-day supply to an 80-day supply.

COMPARISON OF MRP AND OPT

MRP (or MRP-II) and OPT have some important differences, and Table B-1 summarizes the key ones. In general, as Table B-1 indicates, the comparison is quite favorable to OPT. However, the algorithm of OPT is kept from the user, and some users may not be willing to operate a system without full knowledge of its underpinnings. Moreover, it is not clear which of these two systems is less expensive. It appears that OPT is less costly to implement, but to obtain it, some vendors require a stream of future payments that are based on a percentage of the savings it achieves.

Neither system has been extensively tested in the complex repair environments that characterize the depots. Both would require massive efforts to implement in the depots as they now stand. The introduction of repair cells (discussed in Appendix A) and other simplifications of depot processes will reduce

TABLE B-1

COMPARISON BETWEEN MRP AND OPT

Principle	MRP or MRP-II	OPT
Usual planning horizon	6 – 12 months	6 – 12 months
Aggregate scheduling for planning	Calculated weekly or monthly	Calculated weekly or monthly
Detailed finite scheduling of resources for execution	None	Bottleneck operations
Focus on resources requirements	Materials only	Labor, equipment, and materials
Resource availability	Assumed to be infinite for all resources except materials	Calculated as scarce or abundant
Operations focused on	All production	Bottlenecks only
Very accurate data required (bills of materials, routings)	All operations	Bottleneck operations
Batch sizing	Fixed	Variable
Flexibility in production (inventories, batching, leadtimes)	Limited	Extensive
Timeliness for producing schedules	Slow	Relatively quick
Utilization and activation of workers	One and the same	Activated workers only used in bottlenecks

the need for elaborate scheduling and control. Moreover, if such systems are still needed, simplification will make them easier to implement and more likely to be successful.

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A modernization strategy for DoD maintenance depots is proposed that increases the performance of current assets and provides a structured contex for making capital investments. That strategy is to simplify processes first and then, where necessary, introduce automated production and inventory controls followed by process automation.

A general case is made for why this strategy makes sense for DoD maintenance depots and specific examples of its application in the depots and the private sector are given.

Techniques for simplification are discussed including group technology and cellular organization. Also, two techniques for automated production scheduling and control are discussed and compared: Manufacturing Resource Planning (MRP-II) and Optimized Production Technology (OPT).

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